

Hybrid system energy simulation for housing

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ABSTRACT

Fossil fuel power plants are still used as a source of energy around the world and have a significant impact on emissions and environmental pollution. To reduce these emissions, renewable energy offers a solution that can be applied in future housing. This study proposes a simulation using HOMER to determine the most cost-effective composition of hybrid renewable energy systems in housing. This simulation can combine photovoltaic (PV) systems, wind power (WP), and a converter that functions to change DC to AC from PV to obtain an alternating current (AC) system. The hybrid combination of PV and WP proves to be the most appropriate and economical choice at the research location. The results of the study showed that the installation of a hybrid system in housing, with an initial investment cost of IDR 107,474.43 million and an annual operating cost of IDR 22,540.23 million, is 41% lower than conventional fossil fuel-based systems. Research data shows that the project's payback period is estimated to be around 11 years. These findings can be recommendations for similar systems in regions with similar contours and geography. Apart from that, positive monetary impacts can provide incentives for policymakers to implement similar hybrid systems, thereby contributing to the goal of global emissions neutralization.

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1. INTRODUCTION

The biggest threat of climate change to the global economy and environment is significant and needs attention. The world contributes about 25% of global greenhouse gas emissions [1]. Countries that use fossil fuel power plants contribute the most to environmental pollution and should be given incentives to reduce emissions of these gases. Indonesia still highly depends on fossil fuel-based electricity generation ($\pm 63.4\%$) for sufficient supply [2]. Indonesia targets a 23% renewable energy contribution by 2025, with solar photovoltaic (PV) installations planned to reach 6.5 GW by 2025 and expand to 14.2 GW by 2030. Indonesia's exceptional solar potential of 207.8 GW, supported by daily irradiance averaging 4.8 kWh/m², represents vast untapped capacity for future development. Current utilization remains minimal at less than 1% of total technical potential, highlighting significant opportunities for renewable energy expansion. Wind power (WP) generators have a huge potential of 154.9 GW, such as in the Siderap and Jenepono areas (South Sulawesi) with a capacity of 200 MW, in Sukabumi with around 170 MW, Garut with around 150 MW, Pandeglang with 150 MW, Lombok with around 100 MW, and areas with a smaller WP potential of 100 MW are in the surrounding East Java area. Hybrid renewable energy system (HRES) includes several

renewable energy generation sources that are compatible with increasing the overall system efficiency [3], [4]. HOMER simulation can complete reliable models and estimates for various geographical conditions and different load profiles with many other assessments [5]-[7]. The HOMER system is used for robust hourly hybrid system simulation. In addition, HOMER also provides suitable results to estimate the feasibility and performance of the system. Solar energy system simulation provides stable results, while uncertainty can occur when simulating wind energy [8]. On the other hand, this tool has the disadvantage of separating important and unimportant loads from the system [9], [10].

The application of renewable energy has received special attention in recent years due to the reduction of emissions and the impact of climate change. A comprehensive analysis of integrated power grid systems, considering various technological advancement factors, has been conducted for future development [11]. The PV system is an excellent energy source because Indonesia is located in an equatorial region with high sunlight availability. Indonesia has various renewable energy sources that are cheap, clean, emission-free, and sustainable, making solar power and wind power the right choices as renewable energy sources for the country.

Advances in overall PV panel system technology increase efficiency and reduce PV unit costs [12], [13]. In addition, housing is very suitable for the utilization of local PV system renewable energy, consisting of large open land [14]. Variation of power, voltage, and current to optimize the network system, in addition to the method of using maximum power point tracking (MPPT) can achieve the objectives of this study [15], [16]. Many researchers have contributed to improving the electrical output and integrated systems in PV panels to reduce fossil fuel consumption. PV system sources are one of the economically feasible hybrid system options to provide electrical energy sources for residential consumers [17]. However, integrating renewable energy into the electricity grid remains a significant challenge, especially due to the large initial investment. Based on the above analysis, the proposed hybrid system combining PV and WP generators has significant potential in Indonesia as an environmentally friendly renewable power source and represents an effective and efficient solution for future development.

Indonesia's residential sector, particularly housing complexes, remains heavily dependent on electricity supplied by the government through the State Electricity Company (PLN). This dependency on centralized fossil fuel-based generation necessitates urgent solutions to address energy security concerns while reducing the environmental impact of current power generation systems. The primary contribution of this research is to demonstrate pathways for transitioning from fossil fuel power plants to renewable energy systems, thereby enabling sustainable green energy implementation in residential housing. This transition will significantly reduce greenhouse gas emissions while ensuring a reliable, clean energy supply that promotes both environmental sustainability and public health for residents.

2. LITERATURE REVIEW

Configurations to optimize hybrid systems in various locations and applications have been done by previous researchers. The hybrid system between PV-WP-diesel batteries is one of the best solutions for residential applications today [18]. A study conducted in Indonesia found that a combination of PV battery systems can achieve 100% renewable energy use [19], [20]. HOMER and RETScreen simulation platforms have been employed in various studies to optimize hybrid power generation system configurations. The above models have provided a solution to the capabilities of hybrid power generation systems and modeling of stand-alone WP and PV systems. However, the representation of temporal variability is of particular concern. Other studies have been conducted on residential renewable energy costs [21]. Modeling is used to determine the appropriate renewable energy system configuration for the current housing [22], [23]. HOMER designs have been used to evaluate biogas systems, stand-alone PV, and integrated renewable energy systems [24], [25].

The current research focuses on the economic aspects of renewable energy systems, which has been conducted in Indonesia, and found that the PV-diesel system can produce around 309.6 kWh of electricity per year for IDR 5,191.99/kWh [26]. A study of the application of microgrid systems in Europe has been conducted, and the analysis of the economic impact of renewable energy systems on households confirms the right choice for a hybrid system consisting of 1.3 kW PV, 9 kW WP, and batteries [27]. Research conducted in Indonesia found that the best configuration in terms of emissions and costs is a hybrid PV-WP and diesel generator-battery (DG-battery) system. A study simulates and feasibility studies battery and PV home power system (HPS) system and can reduce net preset cost (NPC) by about 59.6% and reduce low cost of energy (LCOE) operating cost by about 80.7% compared with conventional methods, and HOMER simulation has provided a reliable and stable energy-saving system and an independent system to generate renewable energy. The comparison of different hybrid systems found that the battery, PV, WP, and diesel power converter systems have the best performance with an LCOE of IDR 6,318.55/kWh, a total NPC of IDR

394,460.32 M, with a return on investment of 40%, and a reduction in fuel consumption and CO₂ of about 95%. The optimization of the hybrid system for PV and WP will meet the household electricity consumption with a payback period of 3.7 to 5.4 years and the COE for the hybrid system varies between 0.46 to 0.56 IDR 9,175.77/kWh. The study of the structure and operating conditions of HRES and HOMER used for the PV/DG/battery hybrid system is a feasible choice in the future, because solar radiation is an available resource. This model can reduce battery requirements by up to 70% and reduce emissions by up to 97% compared to diesel generator (DG). HOMER simulations have been used in economic and environmental surveys and cost of energy (COE) selection, NPC, random forest (RF), and greenhouse gases (GHG) with a reduction in GHG emissions of around 2,889.4 kg/year and renewable energy of around 98.3%. HOMER is also used for simulation and research with an environmentally friendly and economical system, with a reduction in emissions and a very significant NPC of 29.7% per year compared to conventional power plants. The study of optimal conditions for smart home energy management with hybrid energy sources in Indonesia contains an economic analysis to encourage families to integrate higher education contribution scheme (HECS) into residential homes. This study shows that hybrid technology configuration is an option for electrical energy using a mixture of renewable energy sources in Indonesia, such as for industry, institutions, commercial, agriculture, and small scale. Comparison of WP/PV on-grid power generation system configurations to be the best option to be implemented for cost and energy savings.

2.1. Previous research

The literature reviews the economic feasibility of HRES systems in various locations around the world, explores HRES systems to provide sustainable and cost-effective electricity, and finds the technical, economic, and environmental conditions for optimal hybrid systems. However, the most effective combination of renewable energy for a particular region is still limited, hampering the paradigm shift towards a green energy future. There is a research gap to identify relevant combinations of future green energy opportunities. This study relies on the existing literature to determine the most effective hybrid system technologies and their potential integration into the future grid system. This study also validates the results of other studies presented in the literature. The results of this study can provide information to policymakers, energy planners, and stakeholders to accelerate the implementation of hybrid systems and achieve an energy future.

2.2. Research contributions

The primary contribution of this research is to develop and validate a hybrid renewable energy system model combining PV and WP technologies for residential housing applications using HOMER simulation software to determine optimal system sizing. This approach enables a comprehensive assessment of cost savings achieved through renewable energy integration in hybrid energy systems for residential complexes. Simultaneously, the study aims to minimize greenhouse gas emissions, which represent the primary driver of global climate change. Through detailed analysis of Indonesia's current electricity generation emissions profile, this research quantifies the potential emission reductions achievable through hybrid renewable power system implementation.

3. METHODOLOGY

3.1. Description and costs

This research was conducted in Indonesia with peak loads such as in Java Island and its surroundings. However, power outages occur during peak hours caused by all available electricity. Around 0.68% of this is still generated by generators [28]. The cost of electricity usage for households consists of household customers R1 to R3, with different costs per kWh depending on the amount of power used. The costs for these customers can be seen from the list from the PLN. HOMER system modeling is a simulation tool for assessing electricity generation opportunities, requiring accurate electricity load determination as the foundation for designing optimal generation and storage facilities [29]. Household electricity consumption data is usually available using monthly electricity bills, which show the maximum demand based on the price and the amount of energy used. The average load is determined using the middle of the respective month. The most recent available data from two years has been used to take into account the ongoing housing growth and the increase in electricity demand as well as the sharp decrease in peak loads at certain times. This results in peak loads in certain months. A synthetic model has been introduced to improve the accuracy of daily demand changes. This model allows for precise calculations of storage units and installation sizes and the data has been calculated as a power factor value of approximately 0.96.

3.2. WP-PV generator

The climate conditions in a place will depend on the particular season. Climate change caused by environmental properties in Indonesia is a concern in research related to WP. In the summer and rainy seasons, it will produce wind speeds that are good enough as a source of electrical energy. Indonesia's astronomical location is between 6° LU-11° LS and 95° BT-141° BT [30]. Areas with tropical climates have the potential to occur throughout the year, thus ensuring efficient PV operation. During the time active rainy season in Indonesia, then on the rainy season months produce high wind speeds produce the potential for WP power plants to operate very well [31], while cloud cover reduces the potential PV generator, so that the generator WP is an alternative source solution that can reduce electricity usage from other sources [32].

4. HOMER AND SIMULATION

HRES systems and energy storage systems are direct steps to reduce emissions, but can indirectly improve the stability of the electricity grid. HRES models are compatible with hybrid sources to improve the overall system efficiency. HOMER simulation is the best and most reliable solution to identify application-specific approach models in various geographic regions and load profiles. HOMER provides load profiles for residential, industrial, and other complexes. Some options may not be financially profitable but are environmentally beneficial. Environmental factors are considered as a result of future emissions from fossil fuel combustion, depending on the pollutants. The proposed system components are PV and WP system modeling, that has provided the most realistic options and have been implemented into an integrated system. This simulation calculates and evaluates the life cycle simulation (LCS), but HOMER can resize all components to the most effective size. The PV size is significant, and the operation and maintenance (O&M) costs can be assumed to be relatively low per unit of installed power (kW). Conversion to a hybrid electric system in the MW range has an efficiency lower than 98%. The difference between the standard test conditions (STC) and the actual value is between 0 and 0.77 [33], [34]. For large models, the highest value can be used, since the design is more efficient. Specific research takes about 0.7. However, for a safety margin, analysis of low to high-value changes has also been done. A battery with 80% efficiency is chosen as the storage unit since it offers the highest energy density and is considered the most appropriate choice for environmentally friendly energy storage [35]. In this study, HOMER introduces a dynamic efficiency range for WP, which varies with the change in wind speed. The HOMER system is a regulated resource and an active generating unit to produce electricity according to consumer demand, with fluctuating voltage and frequency to support the electricity grid. Replacing the WP of the entire system and adding more PV panels is a solution which will drive the need for larger storage capacity because the electricity supply will be intermittent.

4.1. Parameter economy

Economic evaluation is a special concern before the project is implemented. In 2021, the assumed discount rate is 6.25% for Indonesia [36]. Indonesia recorded annual inflation of 3% in April, driven by rising transportation costs as >190 million urban residents celebrated their return to their hometowns. This inflation decreased compared to the previous month of 3.05 percent but was still within the central bank's target range of 1.5-3.5%. The increase in the consumer price index from 103.3 (April 2023) to 106.4 (April 2024). This increase occurred in Gorontalo with an inflation rate of 4.65%, and in Papua by 1.78%. The increase occurred due to geopolitics in the Middle East and high interest rates in the US, so the central bank raised the benchmark interest rate by 25 basis points to 6.25%. To control inflation and maintain the stability of the rupiah, the benchmark interest rate has been raised by 275 basis points since August 2022. The uncertainty of the simulation will depend on the sensitivity value selected. The PV model can be used for 25 years and is a guarantee of the manufacturer's standard product [37]. For 15 years, conducting accounting simulations for unforeseen events and facilitating the overall financial assessment of projects.

4.2. CO2 emissions

CO2 emissions are one of the major contributors to global warming, with carbon emissions increasing by 11% by 2025, and pose a significant health hazard to humanity worldwide. Reducing emissions has become a key target for achieving worldwide consensus as part of the framework for reducing carbon emissions. Indonesia's global warming process, which produces 699 metric tons of carbon emissions per year, is now part of the framework modeled for international CO2 trading, which is used as a product for intermediate consumption. Indonesia has measured emissions and carbon dioxide to save energy [38]. The average daily electricity consumption for all institutions is 46,559 kWh, currently contributing 23.82 tons of CO2 daily [39].

5. RESULTS AND DISCUSSION

5.1. Optimization system design

System dimensioning and creation have been done using HOMER simulation. The input electrical load data for one year has been provided to perform the simulation. Monthly global irradiance, monthly clarity index, and monthly average wind speed for the location are available and included in the HOMER simulation. Simulation and optimization for performance characteristics, annual electrical load curve, electricity production, hybrid fraction, and emissions have been done. The following load control strategies have been used during the simulation, and additional grid centers have been considered to ensure the product meets the demand requirements. Different simulations are ranked based on different component adjustments based on total LCC and NPC [40].

The LCS layout has been determined in such a way that HOMER has determined the optimal system consisting of a PV array with a capacity of 3010 kW, a system converter with a capacity of 1930 kW, and a WP with a capacity of 500 kW. The assumption above is one of the realistic projects related to the availability of space around the housing complex. HOMER simulation is the best combination for efficient performance in this open space location. The simulation results show that the amount of energy is 3830.1 MWh/year or 19.1% of the energy from PV and 4532.6 MWh/year or 22.6% of the energy from WP. Available approx 41.5% of electricity from hybrid energy sources in the system. The actual monthly energy production from each additional source can be obtained from the simulation. Most likely because the production curve and load of the PV-based system are very aligned and the purchase price is high, the simulation results are highly dependent on input parameters such as investment costs, new generating facilities, and other costs [41].

PV panels cost IDR 8,163,500.00 according to various sources; LCS will not use additional WP. The electricity mix during months with high residential activity is highly dependent on grid supply because, throughout the year, electricity comes from new energy sources. Fossil energy production peaks during the day, driven by PV output. In the rainy months, the increase in average wind speed causes an increase in wind turbine production, indicated by an increase of more than 100% per hour. This results in electricity being connected to the commercial electricity grid, reducing the need for waste storage infrastructure and reducing construction costs. The technical potential of renewable electricity in the residential sector is enormous, and the social acceptance attribute provides important support from local residential users. Energy planning, development of renewable electricity grid infrastructure, and implementation of future hybrid energy systems can use the results of the above research as a benchmark.

5.2. Economy

The designed system is expected to operate for 25 years, with an estimated annual interest rate of about 4%. It is estimated that by taking into account future savings by reducing the need for direct purchase of grid electricity, cumulative savings of about IDR 106,125.50 million can be achieved. The simulation results show that the initial installation investment required is about IDR 107,431.66 million, and the annual cost is about IDR 1,002,151.26 million. The payback period is estimated to be about 11 years and the inverter can be used for about 15 years with the LCS operational cost still smaller. However, the operational cost continues to decrease with increasing savings for the following year. The internal rate of return (IRR) of about 7.6% has made a positive contribution to increasing electricity generation and income and exceeds the investment and financial costs.

5.3. Emissions

This hybrid system can achieve operational emission reductions of around 42.4%. Indonesia and the World Bank are working together to develop a virtual carbon trading plan. In 2021, Indonesia identified PV energy as a major resource, and the Ministry of Energy and Mineral Resources estimates a huge potential of around 3,294 GW. Based on data from the Institute of Essential Services Reform (IESR), the greater potential is around 7,715 GW, because Indonesia is strategically located on the equator, resulting in a global average daily horizontal irradiance (GHI) of 4.8 kWh/m², surpassing other countries. In addition, Indonesia has set targets and maximized this potential as stated in the National Energy Master Plan. By 2025, Indonesia seeks to achieve an installed PV generation capacity of around 6.5 GW and increase it to 17.6 GW by 2035. The policies that have been stated in government regulations mean that Indonesia is currently focusing on supporting the PV industry, such as floating systems. Solar panels, residential rooftop solar power, and utility-scale solar power plants. Floating PV systems present a promising opportunity, taking advantage of Indonesia's vast maritime territory, and are outlined in an analysis by the National Research and Innovation Agency (BRIN) in 2022. With around 5,800 lakes covering an area of 5,868 square kilometers (km²) and calm seas of 708,000 km², Indonesia has plenty of room for floating PV systems. The safety of PV panel installation is also proven by the absence of tropical storms in Indonesia for the past 50 years [42].

One of the realizations of floating PV potential in Indonesia is the Cirata Reservoir in West Java which was inaugurated at the end of 2023. Indonesia has the largest floating PV in Southeast Asia, the Cirata Floating PV with a water area of 225 hectares and a capacity of 192 MW. This success opened a dialogue regarding expansion plans between the state-owned electricity company and Abu Dhabi renewable energy company Masdar. The construction of Cirata PV phase II has increased the total installed capacity to 500 MW. In 2024, the Ministry of Energy and Mineral Resources plans to add a hybrid floating solar power plant project located in Singkarak (West Sumatra), Saguling (West Java), and Karangkates (East Java). Another great potential comes from the use of rooftop PV for households with a potential capacity of around 32.5 GW. Rooftop PV will also operate in 2023 with a capacity of around 95 MW, with a contribution from the household sector of 72% of total production. Electricity consumption in Indonesia has been dominated by the household sector for at least the past sixteen years, according to data from the Ministry of Energy and Mineral Resources. In 2020, the household sector contributed 50.8% of national electricity usage. In early 2024, the Indonesian government amended the Regulation of the Minister of Energy and Mineral Resources No. 26/2021 to encourage the household sector's transition to renewable energy by removing the previous cap on PV installation of 10-15% of total installed electricity capacity. The Indonesian government is actively encouraging the expansion of rooftop PV for households to increase the renewable energy mix. By 2050, rooftop PV power generation is expected to reach around 30% of government buildings and 25% of high-end housing and apartment complexes, further contributing to renewable energy practices.

5.4. Comparison of literature and research

HOMER simulation to compare the LCOE of the hybrid energy system (PV, WP) and emission results for housing has provided information about housing energy requirements and PV and WP source data in the research location. LCOE determined from LCS is IDR 1,272.18/kWh is relatively low and continues to decrease. Actual LCOE and CO₂ emissions will depend on housing energy requirements, location, PV and WP source data, system design, and other configuration parameters. In addition, there is the reduction of investment cost and operation and maintenance cost due to economy of scale, reduction of production cost, and so on.

HOMER has provided sensitivity analysis for PV, WP, and battery hybrid systems. The parameters entered will affect the performance and sensitivity analysis of this hybrid system. Various parameters in sensitivity analysis can help determine the optimal system design and configuration and maximum performance efficiency. In addition, climate change in this study is not discussed in more depth. The application of other parameters and costs will increase production efficiency and help identify general concepts in energy use in housing and industry.

6. CONCLUSION

The PV and WP energy configuration analysis has been conducted to evaluate the feasibility and cost analysis. The results of the analysis illustrate that the combination of PV, WP, and batteries is still the optimal choice for the electricity grid system in Indonesia. Reducing the need for storage facilities and utilizing WP energy has been carried out optimally, thus helping to reduce the load on the PV cells. The COE system and the return on investment of the project provide a reasonable value for implementation. The use of PV and WP will result in minimum operational costs for 25 years with minimal performance and costs. The total reduction in CO₂ emissions is determined to reduce annual costs, considering the carbon trading system method, which contributes to a higher return on investment. The hybrid system between PV and WP is the right and economical choice for electricity production, and studies show that in certain geographic locations, the installation of HRES can be done.

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C : Conceptualization

M : Methodology

So : Software

Va : Validation

Fo : Formal analysis

I : Investigation

R : Resources

D : Data Curation

O : Writing - Original Draft

E : Writing - Review & Editing

Vi : Visualization

Su : Supervision

P : Project administration

Fu : Funding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [AJ], upon reasonable request.

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